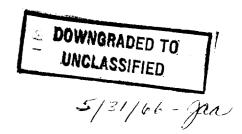
#### RYAN ELECTRONICS

RYAN AERONAUTICAL COMPANY 5650 KEARNY MESA ROAD SAN DIEGO 12, CALIFORNIA

VOLUME III

LEM LANDING RADAR

FIRST DESIGN REVIEW DATA PACKAGE (U)



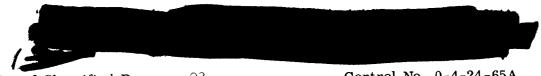
(TABLE 2-1, 2-la AND SECTIONS 2.3 AND 2.4)

65 407

24 APRIL 1965 REPORT NO. 53969-22-3

TYPE II DOCUMENT
PREPARED FOR
CONTRACT GX-807201-L61
RADIO CORPORATION OF AMERICA

DOWNGRADED TO DINCLASSIFIED



No. of Classified Pages: 23 (Excluding Title Page)

Control No. 0-4-24-65A Copy No. 47

NOTICE

#### The following mages are classified.

2-7	2-23	2-34
2 <b>-</b> 8	2-24	2 <b>-3</b> 5
2 <b>-</b> 8a	2-27	2 <b>-3</b> 6
2 <b>-8</b> b	2-28	2 <b>-3</b> 8
2-14	2-29	2 <b>-3</b> 9
2-20	2 <b>-3</b> 0	2-40
2 <b>-</b> 21	2-31	2-41
2 <b>-</b> 22	2 <b>-33</b>	

#### FOREWORD

Ryan Aeronautical Company submits this First Design Review Data Package for the Landing Radar Subsection of the Lunar Excursion Module (LEM) in accordance with RCA Message No. L61-775, dated 17 March 1965.

This report is divided into three volumes:

- (a) Volume I (Report No. 53969-22-1) comprises Section 1, Section 2 (exclusive of classified portions) and Section 3.
- (b) Volume II (Report No. 53969-22-2) comprises Sections 4 through 12.
- (c) Volume III (Report No. 53969-22-3, confidential) comprises Table 2-1, 2-la and Sections 2.3 and 2.4.

#### TABLE OF CONTENTS

(Volume III)

Section			Page
2.3	ANALYS	IS OF OPERATION	2-14
	2.3.1	Operation Over Nominal Trajectory	2-14
	2.3.2	Signal-to-Noise Ratio Budgets	2-14
	2.3.3	Error Budgets	2-24
2.4	PERFOR	MANCE ENVELOPE	2 <b>-</b> 36
	2.4.1	Pitch Limits	2-36
	2.4.2	Transient Effects	2-38
		2.4.2.1 Altitude Step	2-41
		LIST OF TABLES	
<u>Table</u>			Page
2-1			2 <b>-</b> 7
2-la			2-10

### Table 2-1. Landing Radar Physical and Operational Characteristics

Type of System	
Velocity Sensor	CW, 3-beam
Radar Altimeter	FM/CW
Altitude Capability	7
Velocity	0 to 25,000 feet <sup>1</sup>
Altimeter	10 to 40,000 feet
Velocity Capability	$V_{xa}$ : -2000 to + 100 fps
	V <sub>ya</sub> : -500 to +500 fps
	$V_{za}$ : -500 to +3000 fps
Weight	
Antenna Assembly (Exclusive of Shroud)	13.62 pounds
Electronics Assembly	11.19 pounds
Total Weight	24.81 pounds
Size (L x W x H)	
Antenna Assembly	20.0" x 24.6" x 6.5"
Electronics Assembly	13.25" x 6.25" x 5.13"
Power Consumption	105 watts dc
Altimeter Antenna	
$\mathtt{T}\mathbf{y}\mathtt{p}\mathtt{e}$	Planar array, space duplexed
Gain (Two-way)	26.7 db
Beamwidth (Two-way)	3.9 degrees fore-aft
Velocity Sensor Antenna	
Type	Planar array, space duplexed
Gain (Two-way)	27.6 db

Beamwidth (Two-way)

3.4 degrees fore-aft

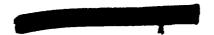


Table 2-1. (Continued)

Transmitters

Type Solid State

Frequency

Velocity Sensor 10.51 gc Radar Altimeter 9.58 gc

Output Power

Velocity Sensor 200 mw
Altimeter 100 mw

Altimeter Modulation Sawtooth FM

Modulation Frequency 130 cps

Deviations 8 mc and 40 mc

Warmup Time 1 minute

Response time 0.1 sec nominal

Outputs

Serial Binary to Computer

Parameter	Limits	Counting Time	Scale Factor
15000 - V <sub>xa</sub>	-2000 to +100 fps	100 m sec	0.5148 fps/count
15000 + V <sub>ya</sub>	-500 to +500 fps	100 m sec	1.002 fps/count
15000 + V <sub>za</sub>	-500 to +3000 fps	100 m sec	0.6857 fps/count
Range	2500 to 40,000 feet	200 m sec	2.155 ft/count
Range	10 to 2500 feet	200 m sec	0.4310 ft/count

Display Outputs

Analog

V<sub>ya</sub>' (-400 to +400 fps) 12.5 mv/fps (±5 volts max.)
V<sub>s</sub>' (-400 to +400 fps) 12.5 mv/fps (±5 volts max.)

Table 2-1. (Continued)

Divid	60	Tra	inc
ונות	se	Tra	. TIIS

V '	(-500 to +100 fps)	19.45 pps/fps
Range	(2500 - 40,000 ft)	2.32 pps/ft
Range	(10 - 2500 ft)	11.6 pps/ft

#### Status Indications

Range Data Good

Velocity Data Good

Range Low Scale Factor

Antenna Position 1

Antenna Position 2

#### Inputs Accuracy

Primary power, antenna position

	Altitude, feet	Accuracy
Range (digital and pulse train)	10-25,000	1% or ±5 ft
•	25,000-40,000	2%

Velocity<sup>2</sup>

city <sup>2</sup>			
v <sub>xa</sub> (	digital)	5-25,000	1.5% or ±.1.5 fps
v <sub>ya</sub> (	digital)	5-200 200-2000 2000-25,000	2% or ± 1.5 fps 3% or ± 3 fps 2% or ± 2 fps
v <sub>za</sub> (	digital)	5-200 200-2000 2000-25,000	2% or ± 1.5 fps 3% or ± 3 fps 2% or ± 2 fps
V <sub>xa</sub> '	(pulse train)	5-200 200-2000 2000-25,000	1.5% or ± 1.5 fps 2% or ± 2 fps 1.5% or ± 1.5 fps
Vya'	(analog)	5-200 200-2000 2000-25,000	2.5% or ± 2.5 fps 3.5% or ± 3.5 fps 2% or ± 2 fps

#### Table 2-1. (Continued)

V\_' (analog) 5-200 3% or ± 3 fps

200-2000 3.5% or ± 3.5 fps

2000-25,000 3% or ± 3 fps

Reliability

Total Failure Rate / 10<sup>6</sup> hrs 177.65

Probability of Mission Success .9996150

#### Notes:

- 1. Partial Operation, 25,000 to 40,000 feet.
- 2. Per cent figures refer to per cent of total velocity.

Table 2-la

### LANDING RADAR REFERENCE DATA BEAM ANGLES

8	19 <sup>0</sup>	581	56"
θ	240	271	36"
1	13°	31'	17"
Ę	20 <sup>0</sup> '	341	38"
φ	34°	221	47".
Y	140	241	20"

#### ANTENNA TILT ANGLES .

Position 1	50°	43'	24"
Position 2	20 <sup>0</sup>	341	38"

#### RANGE SCALE FACTORS\*

High Deviation	The state of the s	
Low Deviation	2.32232 cps/ft	

#### DOPPLER COEFFICIENTS\*

• [	7 cos v. cos Ł	2 oin ~	2 cos A sin f	2 008 1
	19.453 ops/fps	4.9968 ops/fps	7.3030 ops/fps	20.778 cps/fps

#### VELOCITY COEFFICIENTS\*

2 cos -1- cos £	4 sin -A	4 cos A sinf	15' cos -Λ-	A ctn &	A tan E.
19.453 cps	1 fps 9.9935 cps	14.606 cps	1 fps 19.479 cps	1 fps cps	1 fps 55.34 cps

Scale factors and coefficients contain no corrections for tracker gain, terrain bias, etc.



#### 2.3 ANALYSIS OF OPERATION

#### 2.3.1 Operation Over Nominal Trajectory

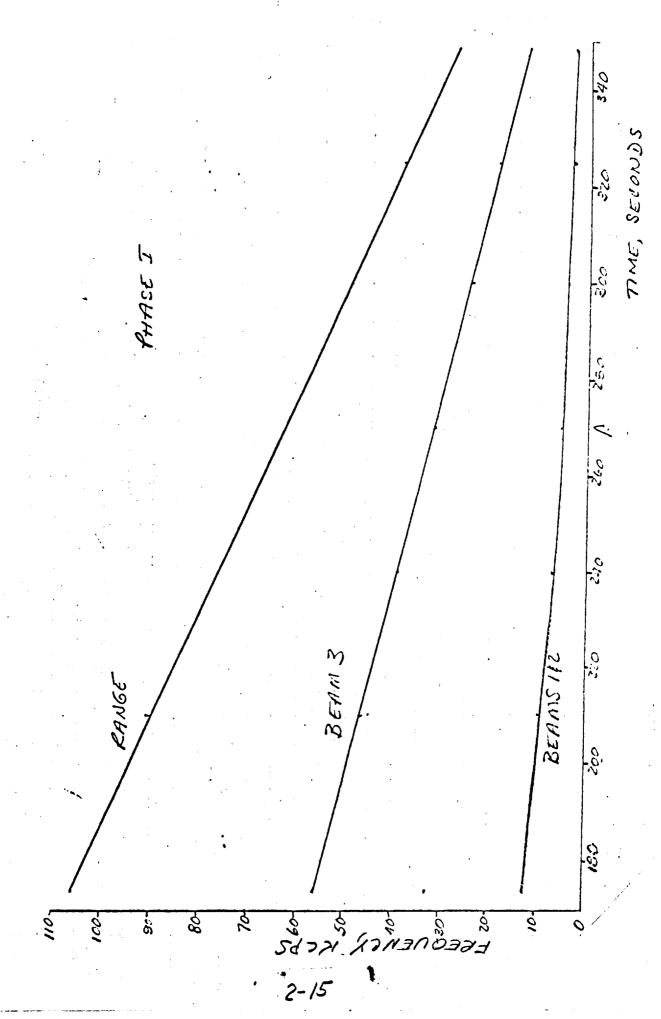
Figures 2-5 through 2-9 give the computed signal frequencies, bandwidths, and beam incidence angles over the trajectory given in Table 1 of the LR specification, LESP-(B)-3600B. Computed signal-to-noise ratios and accuracies are given in the following paragraphs.

#### 2.3.2 Signal-to-Noise Ratio Budgets

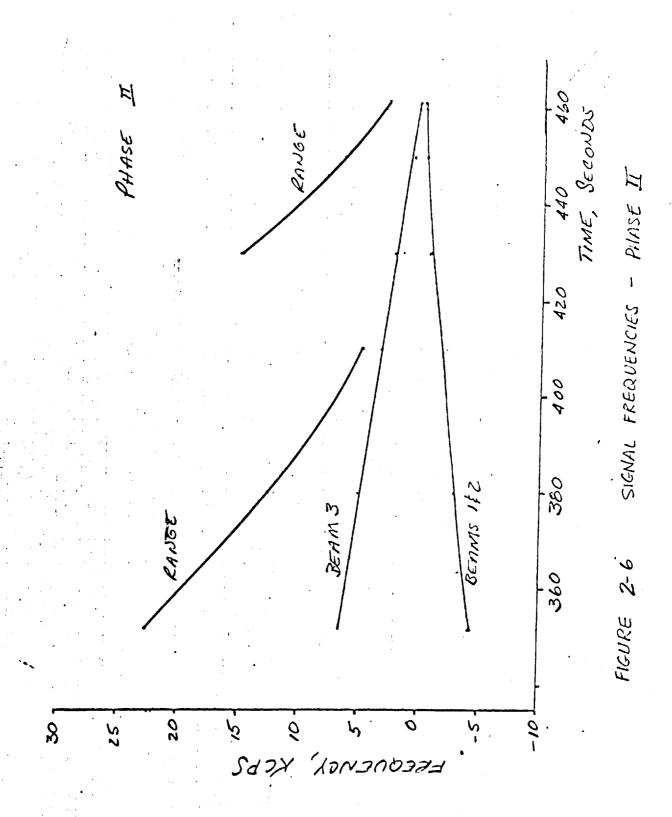
Budgets for signal-to-noise ratios are given in Tables 2-2 and 2-3 for the altimeter and velocity sensor, respectively.

The Altimeter S/N Budget shows a nominal S/N of 8.9 db at 40,000 feet. Equipment tolerances taken in a worst case manner may reduce the signal-to-noise ratios by 2.2 db, reducing available S/N to 6.7 db minimum. The minimum margin, therefore, is 3.7 db.

The velocity sensor S/N Budget shows a nominal S/N of 4.8 db at 25,000 feet for Beam 3. Equipment tolerances which may reduce the signal-to-noise ratio amount to 2.2 db, reducing the available S/N to 2.6 db minimum. The minimum signal-to-noise ratio is, in this case, 0.4 db below the nominal acquisition level of 3 db. However, the signal-to-noise ratio required for a high probability of acquisition is lower than the nominal at wider bandwidths. For the bandwidth expected for Beam 3 at 25,000 feet (1800 cps), a 95% acquisition is attained at a signal-to-noise ratio of about 2.4 db, or 0.6 db below the nominal requirement ( cf. Figure 2-12). Beams 1 and 2 of the velocity sensor are more favorable, each having a nominal signal-to-noise ratio of 6 db at 40,000 feet.



IRE 2-5 SIGNAL FREQUENCIES - PHASE I



2-16

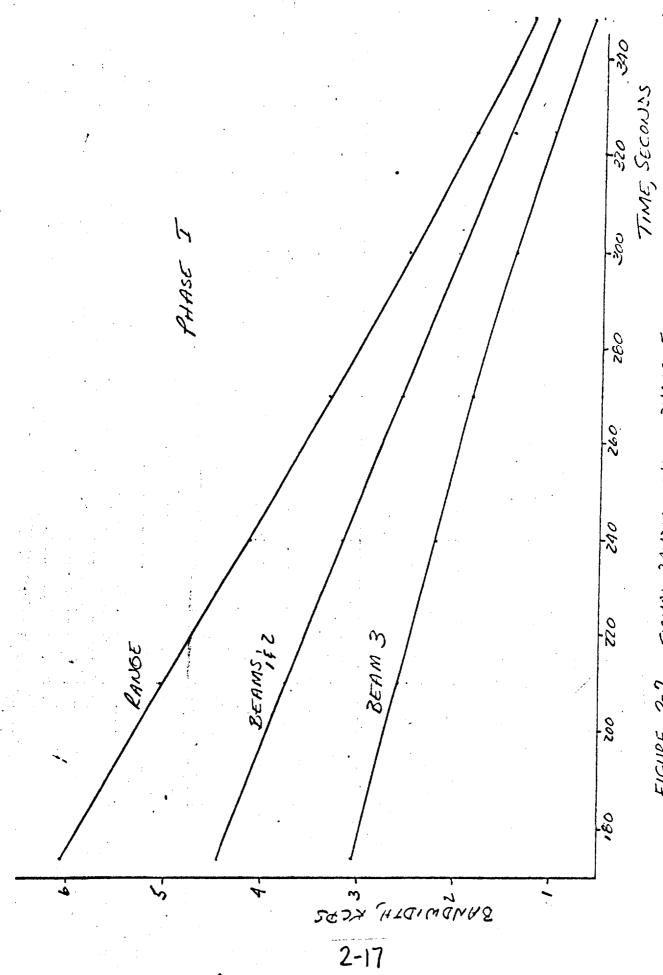
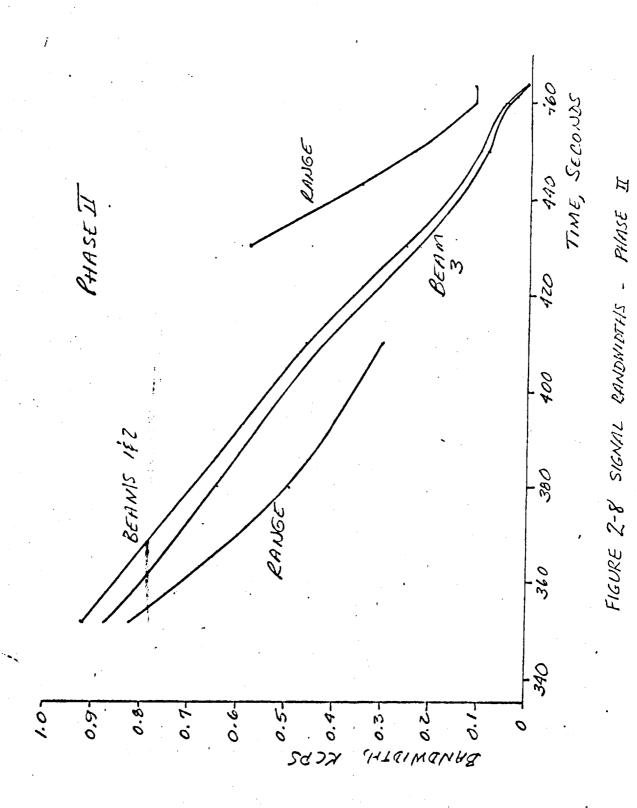


FIGURE . 2-7 SIGNAL CANDWIDTHS - PHINSE I



2-18

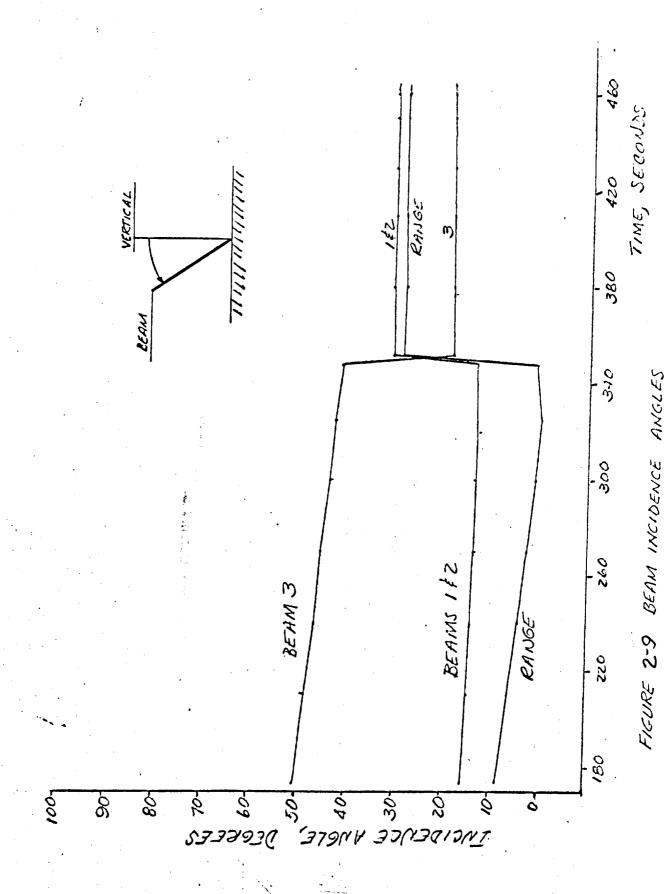




Table 2-2 S/N Budget Altimeter Refer to Figure 2-10

		Nomina	al [		[Values in db (w)	
Parameter		Value		Signal	Noise	Tolerance
Transmitter power	· P <sub>t</sub>	0.05	w	-13.0		+3.0
Waveguide Loss	Lg	-0.2	db	- 0.2		-
Pattern Parameter	K	0.25		- 6.0		+1, -0
Antenna Gain	G <sub>O</sub>	26.7		26.7		+0.5 -0
Wavelength (Squared)	$\lambda^2$	0.102	7 ft	-19.8	·	negl.
Cross Section	$\mathcal{O}_{b}$	-16.3	db	-16.3		-
Cos O	_	8.2	deg	- 0.1		-
$(4\pi)^2$	-	-		-22.0		-
Altitude (Sq'd)	h	40,000	ft	<b>-</b> 92.0		-
Conversion loss	$L_{c}$	-8.0	đb	- 8.0		-1.0 +2.0
Receiver excess Temp. Ratio	$t_{\mathbf{x}}$	5.8	dъ		+5.8	
Constant	kT	-204	dbw		-204.0	-
Tracker Bandwidth	$\mathtt{B}_{t}$	3540	cps		+35.5	+0.2
Signal loss in filter	ı	3.1	db	- 3.1		
Totals (dbw)				·· 153 <b>.</b> 8	-162.7	+6.7, -1.2

Nominal Signal-to-noise 8.9 db
Required Signal-to-noise 3.0
Maximum Negative Tolerance -1.2
Acquisition Circuit Tolerance ±1.0
Minimum Margin 3.7

Note: Based on Nominal Trajectory at 40,000 feet



Table 2-3
S/N Budget Velocity Sensor
Refer to Figure 2-10

	Nominal		Values in db (w)	
Parameter	Value	Signal	Noise	Tolerance
Transmitter power				
Per Beam $P_{t}$	0.05	-13.0		+3.0, -0
Waveguide Loss L	-0.2 db	- 0.2		-
Pattern Parameter K	0.25	- 6.0		+0.5 -0
Antenna Gain G	27.6 db	+27.6		-0
Wavelength $\lambda^2$ (squared)	0.0936 ft	-20.6		negl.
Cross Section* $C_o$	-25.7			-
Cos 0 *	45.4°	- 1.5		-
$(4\pi)^2$	-	-22.0		-
Altitude (squared) *h	25,000 ft	-88.0		-
Conversion loss L	-8 db	- 8.0		-1.0 +2.5
Receiver excess Temp. Ratio t	5.8 db		+5.8	
Constant kT	-204 dbw		-204.0	-
Tracker Bandwidth B	3300 cps		+ 35.2	<u>+</u> 0.2
Signal Loss in Filter	0.8 db	- 0.8		
Totals		-158.6	-163.7	+6.7 -1.2

Nominal Signal-to-noise 4.8 db
Required Signal-to-noise Ratio +3.0
Maximum Negative Tolerance -1.2
Acquisition Circuit Tolerance +1.0 db
Minimum Margin -0.4

<sup>\*</sup>Variables of Trajectory - Values given for Beam 3 at 25,000 feet.



)

The S/N Budgets are based on the worst case conditions of the trajectory given in Table 1 of LESP-(B)-3600B. Backscattering cross-sections were computed by interpolation of the values given in Table 6 of that specification. Definitions of the items in the S/N Budgets are given below:

Transmitter power:  altimeter is reduced by 3 dl because of a primary sidelol
---

•	Waveguide loss:	Loss in interconnecting waveguide
•	Pattern parameter:	Constant arising in integration of

transmitting and receiving antenna patterns.

Antenna gain: Square root of transmitting and receiving antenna gain product.

. Wavelength: Microwave wavelength

Cross section:

Backscattering cross section per unit area.

Cos 0: Cosine of incidence angle of beam, measured from vertical.

Altitude: LEM altitudeConversion loss: Conversion loss of mixer

Receiver excess temperature
ratio: Combined excess noise of mixer

and preamplifier.

Constant (kt):

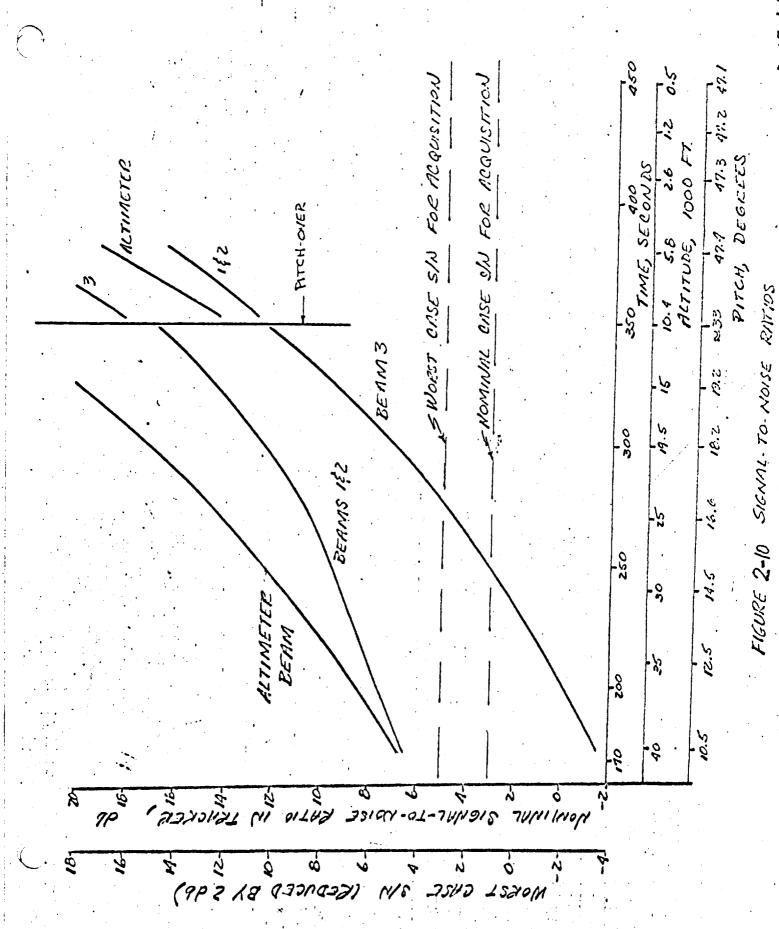
Boltzmanns constant x standard

Tracker bandwidth: Noise bandwidth of tracking filter.

temperature.

. Signal loss in filter: Loss of signal power in tracking filter.

Computed signal-to-noise ratios for the trajectory of Table 1 of LESP-(B)-3600B are given in Figure 2-10.





The signal-to-noise ratio (SNR) required for lock-on, specified as 3 db, is a nominal value which applies for signal frequencies greater than about 3 kc. The operation of the acquisition circuit is such that wide band signals are easier to acquire than narrow band signals of comparable strength. Reliable acquisition (probability greater than 95%) at the specified level has been demonstrated with the breadboard. The results of these tests are indicated in Figure 2-11.

These curves are based on the same data plotted in Figure 3-31, in the detailed discussion of tracker design. The signal-to-noise ratio is defined slightly differently there, the loss in the tracker filter having been neglected. This loss is included in the definition of signal-to-noise ratio as used throughout this section.

The signal-to-noise ratios required to give a probability of detection of 95% are plotted from the data of Figure 2-11 in Figure 2-12. The narrow band signals are more difficult to acquire because of the slow fading rates associated with them. Bandwidths less than about 1 kc are very unlikely at high altitude.

#### 2.3.3 Error Budgets

Error Budgets for the velocity sensor and altimeter are given in Tables 2-4 and 2-5. The errors were computed by the Landing Radar Performance Analysis Program (See Third Quarterly Report, Report No. 53967-3-2, Appendix D). Computed errors for the trajectory of Table 1 of LESP-(B)-3600B are given in Figures 2-13, 2-14 and 2-15.

The error curves do not include the contribution of the error in the 150 kc bias frequency. It is recommended that steps be taken to eliminate this source of error by (1) Sampling the bias frequency for reference, or (2) Using a frequency derived from the computer for the bias frequency.

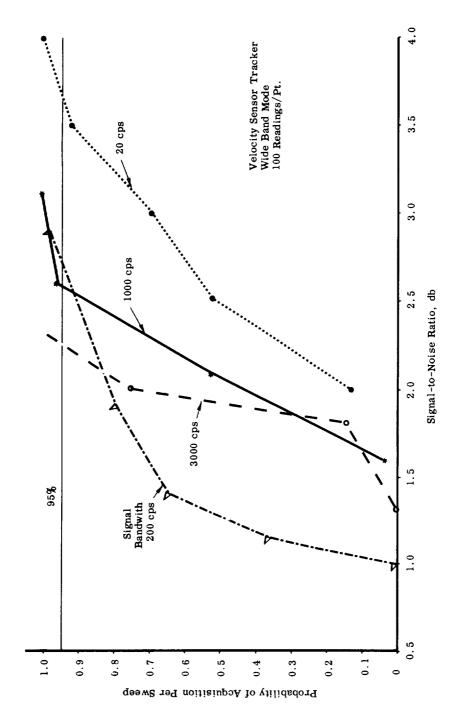


Figure 2-11 Measured Acquisition Probabilities

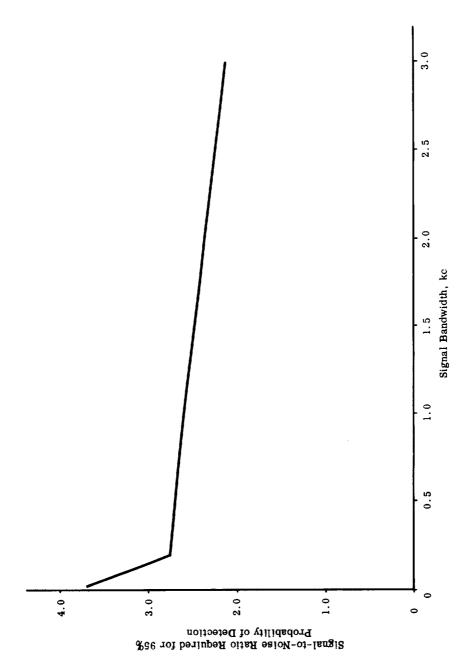


Figure 2-12 Required S/N vs Signal Bandwidth



# TABLE 2-4. VELOCITY SENSOR ERROR BUDGET

ERROR SOURCE	APPLICABLE TOLERANCE	ERRO	ERROR AT 25,000 FEET IN FPS	TET IN FPS (36)
		BEAM	BEAMS 1 AND 2	BEAM 3
boresignt Tolerance	E-Plane + 5 Min. H-Plane $\frac{1}{2}$ 8 Min.	+ 1	+ 4.91	+ 3.55
Installation angles	+ 3.1 mr each axis	<b>`+</b> ' ı	+10.90	+ 7.48
Transmitter Frequency Drift	+ 5 mc	+ •	+ 0.13	+ 0.73
VCO Drift	- 2.5 + 2.5 kc	2.0-	-0.27 + 0.47	- 0.25 + 0.44
Tracker Loop Gain Variation	+ 15% and effects of noise, etc.	-0.3	-0.34 + 0.27	- 1.72 + 1.44
Preamp slope Terrain bias	To per LESP-(B)-3600B, AM.1		+ 3.32	- 0.44 - 1.20
Resultant Beam Bias Errors		+ 1.6	1.6 ± 12.0	- 3.7 + 8.4
	DISPLAY OUTPUTS	(See Figures 2-8a	3a and 2-8d)	
,		∆ Vxa'	∆ Vya'	^*Vza'
Resultant Bias Errors		-1.65 + 11.47	+ 18.55	+0.70 + 1.93
Fluctuation Errors		+3.60	+ 14.95	+ 2.58
Rinnle	ing 2-8		i	ı
)-144-ii	F18. <-> &	9-7	0.17	+ 0.12
Converters	+0.16 FPS + 1% of component		0.28	+ 6.27
Over-all errors, display FPS Percent	Total Vel=2020 FPS	14.57 0.72	23.83	7.75 2.07
* 日 : com com to com to x				

\* Figures for Vza' are for altitude of 2600 feet and total velocity of 374 FPS since Vza' exceeds its limit of 400 FPS at 25,000 feet.

+ 0.21

TABLE 2-4 (Cont'd)

DIGITAL OUTPUTS

APPLICABLE TOLERANCE

ERROR AT 25,000 FT IN FPS (3)  $\frac{\int_{xa}^{xa}}{+1.15 + 10.27}$ 

Resultant Bias Errors

ERROR SOURCE

Error in 150 kc Bias\*

Fluctuation Errors

Quantization

+ 0.5

± 0.7 ±14 .36

+ 1.0

+ 0.31 + 0.16

Bandwidths per Fig. 2-5 and Fig. 2-6

0.4 sec counting time S/N's per Fig. 2-8

± 10 cps

1.41 28.5

12.8

1.27 25.6

0.63

Total Vel = 2020 FPS

\*This error is not included in error curves.

Over-all Errors, Digital

Per Cent

# ERROR AT 25,000 FEET IN FEET(30)

9·<sub>†</sub> +

Boresight Tolerance

Installation Angles Transmitter Frequency Drift

VCO Drift Tracker Loop Gain Variation

Preamp slope
Terrain bias
Modulation rate
Fluctuation
Quantization
Doppler Compensat:

Doppler Compensation Rias Fluctuation
Resultant Bias Error
Resultant Fluctuation
Over-all error digital

Per Cent

## APPLICABLE TOLERANCE

TABLE 2-5 ALTIMETER ERROR BUDGET

H-Plane  $\frac{1}{2}$  5 Min. E-Plane  $\frac{1}{2}$  8 Min. - 3.1 mr each axis

-2.5 + 2.5 kc + 15% and effects of

noise, etc.
Roll-off from 5.65 kc

Go per LESP-(B)-3600, AM.1

 $\frac{+}{2}$  0.5% 0.4 sec counting time S/N = 14 db

Bandwidth = 3300 CPS

-2.7 ± 4.7 -41.6 ±31.0

- 1.0 - 3.4 + 125.4

+10.9

0.47+

+13.9 ± 30.1 +43.5 -34.8 ± 132.9

9.98+

193.4

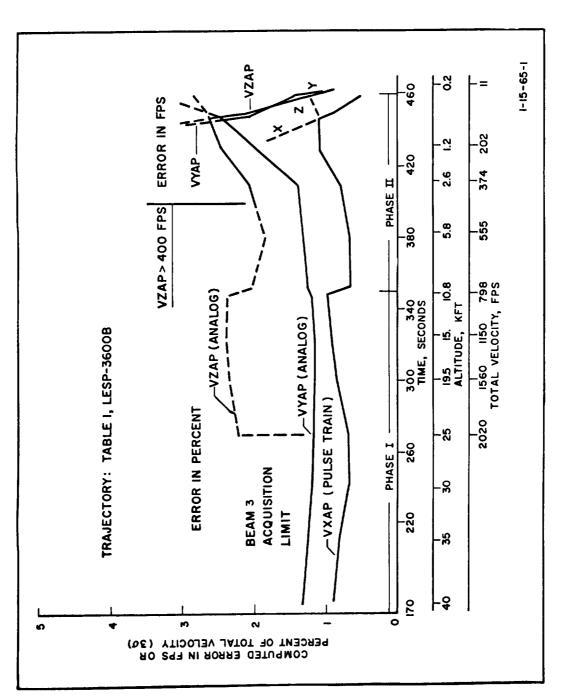
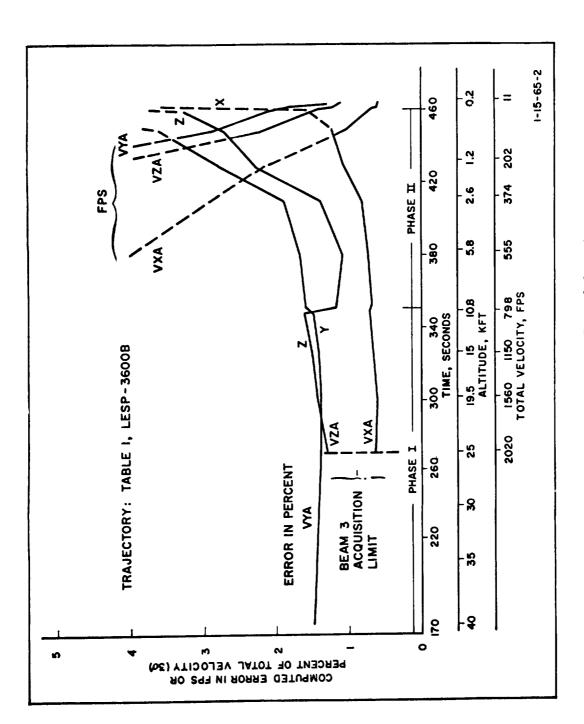


Figure 2-13 Accuracy-Display Outputs



 $(\ \ )$ 

Figure 2-14 Accuracy-Digital Outputs

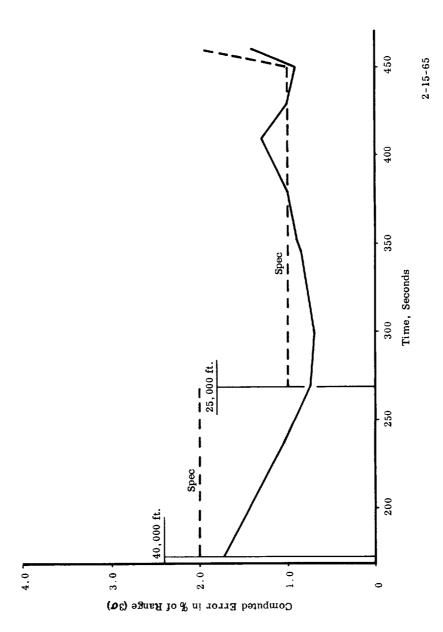


Figure 2-15 Range Accuracy



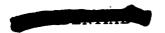
The error budgets and curves do not include allowance for errors in the counting interval, since this is controlled by circuits not under the control of the LR. Timing errors required to cause an error of one foot per second in  $V_{xa}$ ,  $V_{ya}$ , and  $V_{za}$ , are 56, 28, and 40 microseconds, respectively.

The quantization error, which is the  $\pm$  1 count error in the high speed counter, is based on a single continuous counting interval. If the counting interval is broken into several shorter intervals, this error is larger. For example, if the sampling consists of five independent intervals, these errors increase by  $\sqrt{5}$  to become

V xa	0.36	FPS
V <sub>ya</sub>	0.69	FPS
v <sub>za</sub>	0.47	FPS

Dynamic errors are not included in the curves presented.

Computed errors in the velocities for a manual descent from hover are given in Figures 2-16 and 2-17.



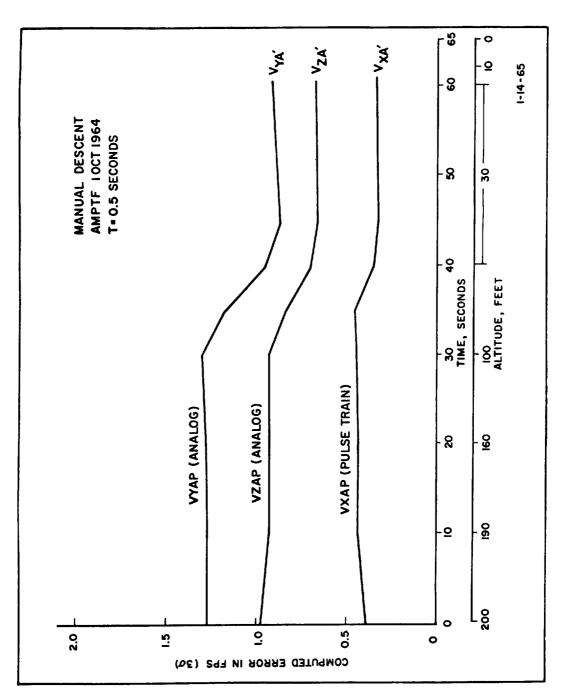


Figure 2-16 Accuracy-Display Outputs

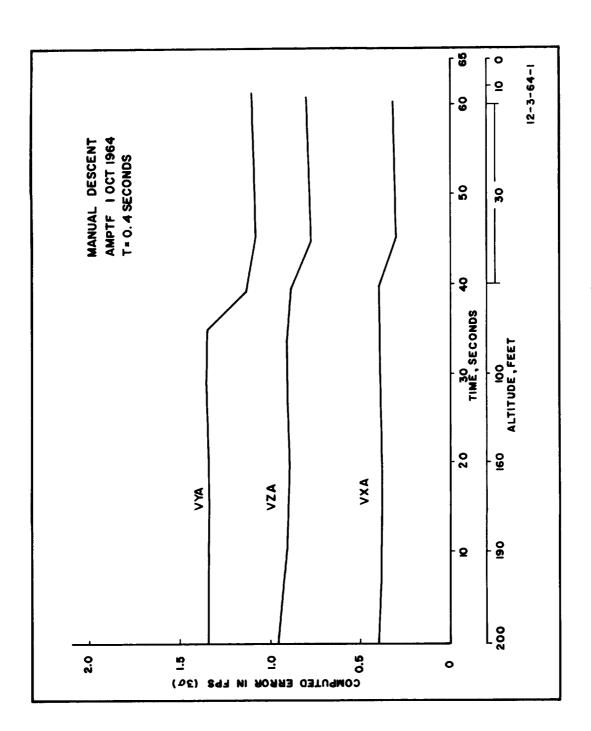


Figure 2-17 Accuracy-Digital Velocities

#### 2.4 PERFORMANCE ENVELOPE

A study is in progress to define the performance envelope of the Landing Radar. Some of the results obtained thus far are given in this section. The performance envelope is defined as the range of altitude, attitude, and velocity within which the LR will operate.

#### 2.4.1 Pitch Limits

As the pitch of the vehicle changes three possible effects are felt in the Landing Radar:

- (1) The signal-to-noise ratio in one or more beams may decrease below the acquisition threshold because of decreased signal return caused by increased range and reduced lunar cross section,
- (2) The signal frequency may exceed the search range, or
- (3) A beam may reach the minimum tracking frequency.

Figure 2-18 defines the vehicle pitch angles within which acquisition can be achieved. The limits above 25,000 feet are for all beams except Beam 3, which is required only from 25,000 feet down. The non-operable region in the center is caused by the frequency of Beams 1 and 2 falling below the minimum tracking frequency. Above this region the doppler frequency for these beams is negative.

For the purposes of computing the data of Figure 2-18, all parameters except pitch are assumed to be nominal (i.e., according to the trajectory given in Table 1 of LESP-(B)-3600B). The nominal pitch angle is plotted for reference.

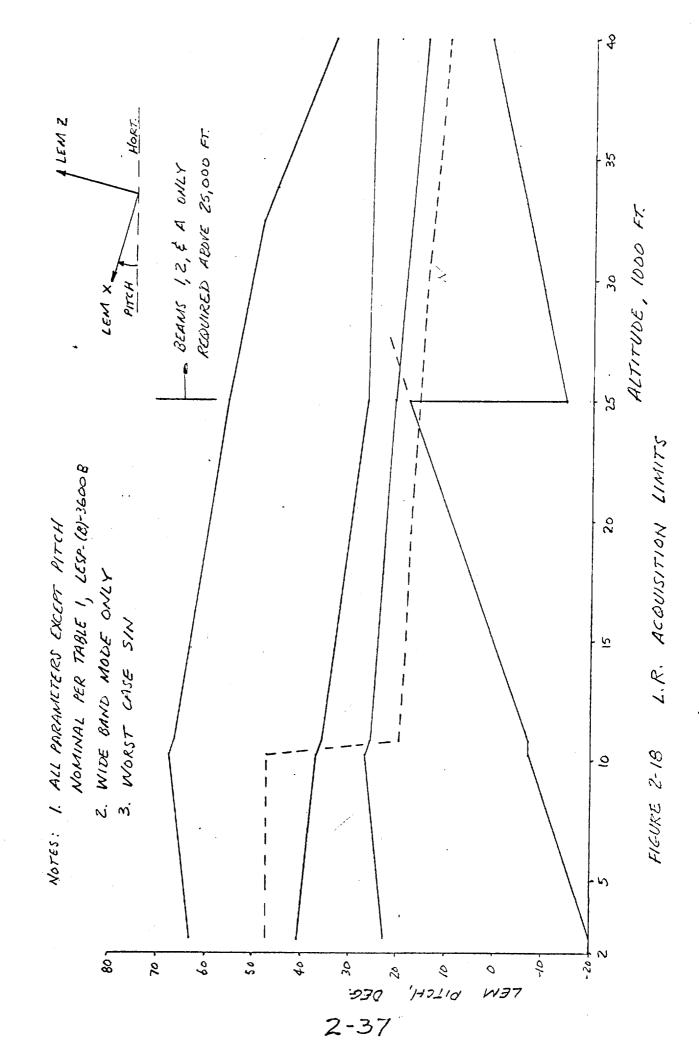




Figure 2-18 is based on operation without the low frequency acquisition circuit, such as is used in the low altitude mode. An investigation is under way at present to determine the limits with the low frequency acquisition circuit active in the high altitude mode.

Drop-out limits, i.e., the pitch limits within which the radar can operate after acquisition, are somewhat wider than those given in Figures 2-18.

Additional work is being carried out to define the performance envelope. The effects of changing the velocity direction and magnitude under a constant Pitch are being studied. Similar results for the low altitude mode are in work.

#### 2.4.2 Transient Effects

Although operation within the zero doppler region is not possible without the low frequency circuit, the frequency trackers will maintain lock if the rate of change of doppler is sufficiently large. Figure 2-19 gives the minimum pitch rate required to maintain lock through the zero doppler region. The amount of improvement in the minimum required pitch rate through zero doppler given by a low frequency acquisition circuit is under study.

Figure 2-20 defines the maximum tracking rates per beam for velocity and altitude for the high altitude mode. The frequency trackers will maintain lock for steady rates of change of velocity and range up to the values given. For the low altitude mode (below 2500 feet range), the maximum beam tracking rates are as follows:

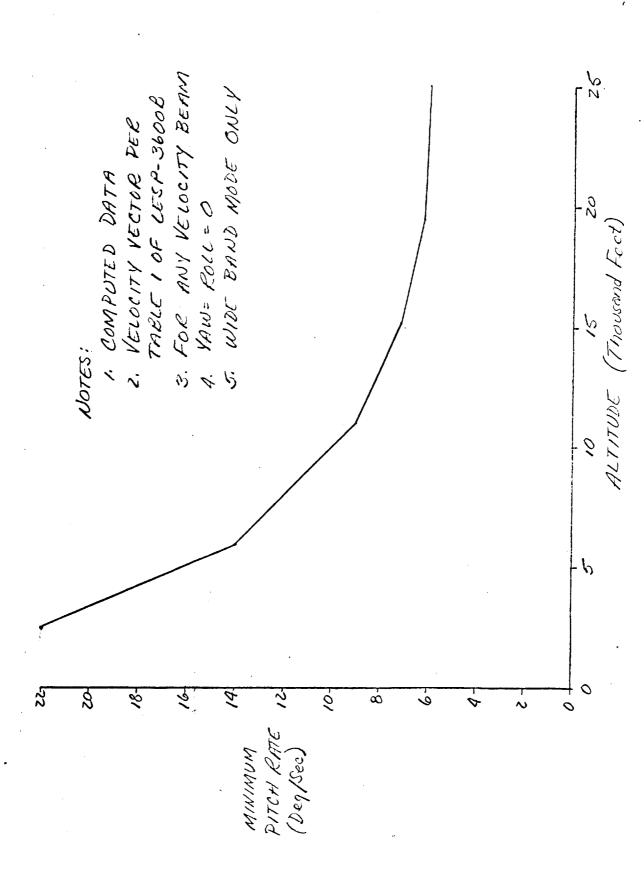


FIGURE 2-19 MINIMUM PITCH RITCS THROUGH ZERO DOFFLER

2-39

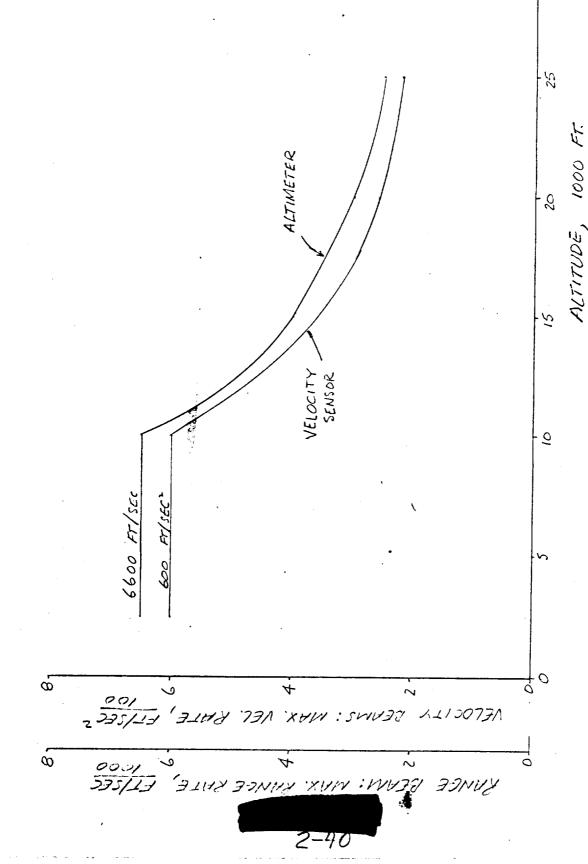


FIGURE 2-20 MAXIMUM TRACKING RATES

#### 2.4.2.1 Altitude Step

If the spacecraft maneuvers or flies over terrain features such that the range beam experiences a step change in range, temporary loss of range data may occur. The step magnitude that can be experienced without loss of lock will vary directly with signal-to-noise ratio and to some extent with signal bandwidth.

The data given below is for an instantaneous step change in range although it is difficult to conceive of situations in which this can actually occur. For example, if the vehicle should fly over a sheer cliff at an altitude of 40,000 feet and a horizontal speed of 4000 ft/sec, it would take almost a full second for the beam to sweep over the range discontinuity.

Step changes in range that can be tolerated without loss of lock are approximately as follows:

Altitude	Altitude Mode	Maximum Step
feet		feet
40,000	High	400
15,000	High	1300
5,000	High	1300
2,000	Low	200